

**Prey Fields and Habitat of Deep Diving Odontocetes:
3D Characterization and Modeling of Beaked and
Sperm Whale Foraging Areas in the Tongue of the Ocean**

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LONG-TERM GOALS

The physical and biological characteristics of the areas inhabited by deep diving odontocetes are poorly understood. Our long term goals are: i) to measure and characterize the biomass in areas and at depths inhabited by beaked and sperm whales; ii) to measure and characterize the physics of these environments; iii) to assemble the characteristics measured (i) and (ii) into a depth integrated, 3-dimensional habitat model; the model will include other dependent and independent data, e.g.,

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chlorophyll and depth, respectively. Our final long term goal is to then apply the habitat model produced to other geographic areas to assess their likelihood as beaked and sperm whale habitat.

OBJECTIVES

The past year has been spent in two primary tasks: i) ongoing analyses of data collected and preparation of publications from the these data, which are primarily from three sources – cruise in 2008 in the Bahamas; ii) continuing data collection and analysis from several cruises off Cape Hatteras concurrent with tagging of short-fin pilot whales (*Globicephala macrorhynchus*) near the Cape Hatteras shelf break.

The technical objectives were: i) to develop statistical models for echoes generated by mutli-frequency scientific echosounders; ii) collect data on prey fields and physical oceanography concurrent with multi-sensor tagging of short finned pilot whales near the Cape Hatteras shelf break.

Prey data for deep diving pilot whales off Cape Hatteras

As part of the current project and a complementary project at Duke, we have been tagging pilot whales off Cape Hatteras and conducting concurrent prey field sampling using a multi-frequency system.

Statistics from Echoes generated by Scientific Echsounders

Over the last two years, a Ph.D. student at WHOI (Wu-Jung Lee) has been investigating a statistical approach to understanding the echoes generated by the scientific echosounders. This portion of the project seeks to understand more of what is in the water column from the echoes, i.e., adding to the normal ‘frequency differencing’ techniques currently in use to differentiate targets.

APPROACH

During the past year, we have worked in analytical as well as data collection modes. Our analyses and synthesis of the prey field and echolocation data from TOTO resulted in the previously cited publication in PLoS ONE (Hazen et al., 2011). St. Laurent and his group have analyzed much of the physical data from the TOTO experiment, and their results are represented the M.Sc. thesis completed by Jay Hooper, which was included with the 2011 report for this project. Finally, we have continued to collect EK60 data in the waters of the shelf break near Cape Hatteras, concurrent with attachment of DTAGs.

The EK60 system makes measurements of the returned energy from one or more targets, which are required to obtain accurate biomass estimates from the total returned echo energy (Foote, 1980a; Foote and Traynor, 1988). The amount of backscattered energy from a single fish is the backscattering cross section or echo intensity. If echo intensity is measured on a log scale it is called target strength (TS). Target strengths are often measured during surveys (*in situ*) or predicted from trawled fish lengths using a TS-fish length regression. Target strength regression equations allow prediction of TS but require large sample sizes, measurements of fish length, and often only include one variable explicitly. For example, if the tilt distribution of a school of fish differs from the tilt distribution of the fish used to derive target strengths, a consistent difference in tilt angle could bias abundance estimates. Converting an acoustic size to a numerical size or the total returned energy to an acoustic abundance estimate relies upon appropriate target strength values for the population.

When fish echoes are too dense to be counted, target strengths are required to convert reflected echo energy to a numerical estimate. The linearity principle as defined by Foote (1983) states that the total returned energy or integrated echo can be divided by a representative backscattering cross section to estimate fish abundance. Fish lengths (L) are used in size-dependent target strength equations: $TS = \beta_1 \log L + \beta_0$ (1) where β_1 and β_0 are parameters that vary among species (Love, 1971; Foote, 1980a; Midttun, 1984). This target strength equation (1) explicitly includes length.

Echo Statistics in Mixed Assemblages

Also as part of this project, a PhD student at WHOI, Wu-Jung Lee, has developed a general theory for the echo statistics due to mixed assemblages of scatterers ensonified by scientific echosounders. For example, if there two sizes of fish interspersed and the numerical densities of the two size classes of scatterers are different, then the echo statistics is distinctly different than the traditional "expected" Rayleigh probability density function. Lee's general theory can handle an arbitrary number of size classes and numerical densities; she has published a paper on the topic.

For the echo statistics work, Lee has developed a general theory for the echo statistics due to mixed assemblages of scatterers. For example, if there two sizes of fish interspersed (as observed in a 2008 experiment at Georges Bank) and the numerical densities of the two size classes of scatterers are different, then the echo statistics is distinctly different than the traditional "expected" Rayleigh probability density function (PDF). Her general theory can handle an arbitrary number of size classes and numerical densities.

WORK COMPLETED

During the spring of 2012 for the second major portion of this award, we continued to work as part of an interdisciplinary research team to tag short finned pilot whales and measure physical and biological oceanographic data at the shelf break near Cape Hatteras, NC. Also, Lee at WHOI continued her analyses and published a paper on her results.

RESULTS

Our processing of the 3-frequency (38, 70 and 120 kHz) EK60 data collected near tagged short-finned pilot whale shows them displaying some feeding behavior at depths where we detected layers of scatterers (Figure 1); we are working to line-up the whale diving with these different layers, and our best estimate from the frequency response (highest at 70 kHz), is a shallow layer of squid.

For the echo statistics work, Lee has applied the theory to broadband acoustic data collected during a September 2008 cruise over Georges Bank that was not part of the field effort for the current project. Both the net samples and resonances in our 1-6 kHz system show consistent presence of two-size-class assemblages of fish. She has applied her theory to the frequencies more relevant to the marine mammal problem, 30-70 kHz. This is driven by the need to look for cues in the acoustic echoes (such as statistical variability) for classifying in terms of the sizes and types ("type" = zooplankton vs squid vs fish, etc.. not at the species level) that echo-locating marine mammals might use to determine prey.

Significant milestones were reached this year on three fronts involving laboratory measurements, modeling, and comparisons with broadband acoustic data collected in the ocean. All pertain to would-be prey fields of echolocating marine mammals and typical frequencies (including broadband signals).

1. *Laboratory measurements*: Broadband acoustic backscattering from live squid was measured in a laboratory at WHOI several years ago. The frequencies were 40-95 kHz and the squid were rotated over all angles of orientation. The data were modeled using a 3-D acoustic scattering model (distorted wave Born approximation) developed by us several years ago. The analysis shows that, to first order, a squid can be modeled as a weak scatterer in that the tissue (and not other parts of the body) dominate the scattering. This modeling of these echo characteristics is important in understanding the foraging behavior of echolocating marine mammals. A paper summarizing the results was submitted in a previous year and published this year (Lee et al., 2012).
2. *Echo statistics from mixed assemblages (narrowband signals)*. This theoretical study formulates an exact expression for echo statistics from mixed assemblages of scatterers of varying sizes and numerical densities. The analysis is relevant to modeling signal cues of foraging echolocating marine mammals. In essence, they may be foraging for prey that is mixed in with other species. The statistics of the echoes from such mixed assemblages give insight into what echo cues the mammal may be locking onto in the foraging process. The results with this new model are superior to those from the commonly used “mixture probability density function (PDF)”. A paper was submitted on our results this year (Lee and Stanton, submitted).
3. *Echo statistics from mixed assemblages (broadband signals)*. Building on the above research, significant progress was made concerning statistics of broadband echoes from mixed assemblages of scatterer. In contrast to the above frequency-domain analysis, this analysis was conducted in the time-domain. The new theory was compared with ocean acoustic data (35-75 kHz) collected on another ONR MMB/NOPP project (Stanton/Jech/Gauss), and a manuscript has been drafted.

IMPACT/APPLICATIONS

The scientific impact of our accomplishments are likely to be significant because as far as we are aware, no field program has ever combined intensive sampling of biological and physical data in the known prey fields of a marine mammal, or any marine megavertebate for that matter. Furthermore, we are combining animal movement information with these physical and biological maps using emerging statistical behavioral ecological models. Also, the experimental and theoretical work conducted by Lee will impact the active acoustics community significantly.

RELATED PROJECTS

Acoustic Resonance Classification of Swimbladder-Bearing Fish at Multiple Scales, T.K. Stanton, J.M. Jech and R.C. Gauss. Award Number: N00014-10-1-0127

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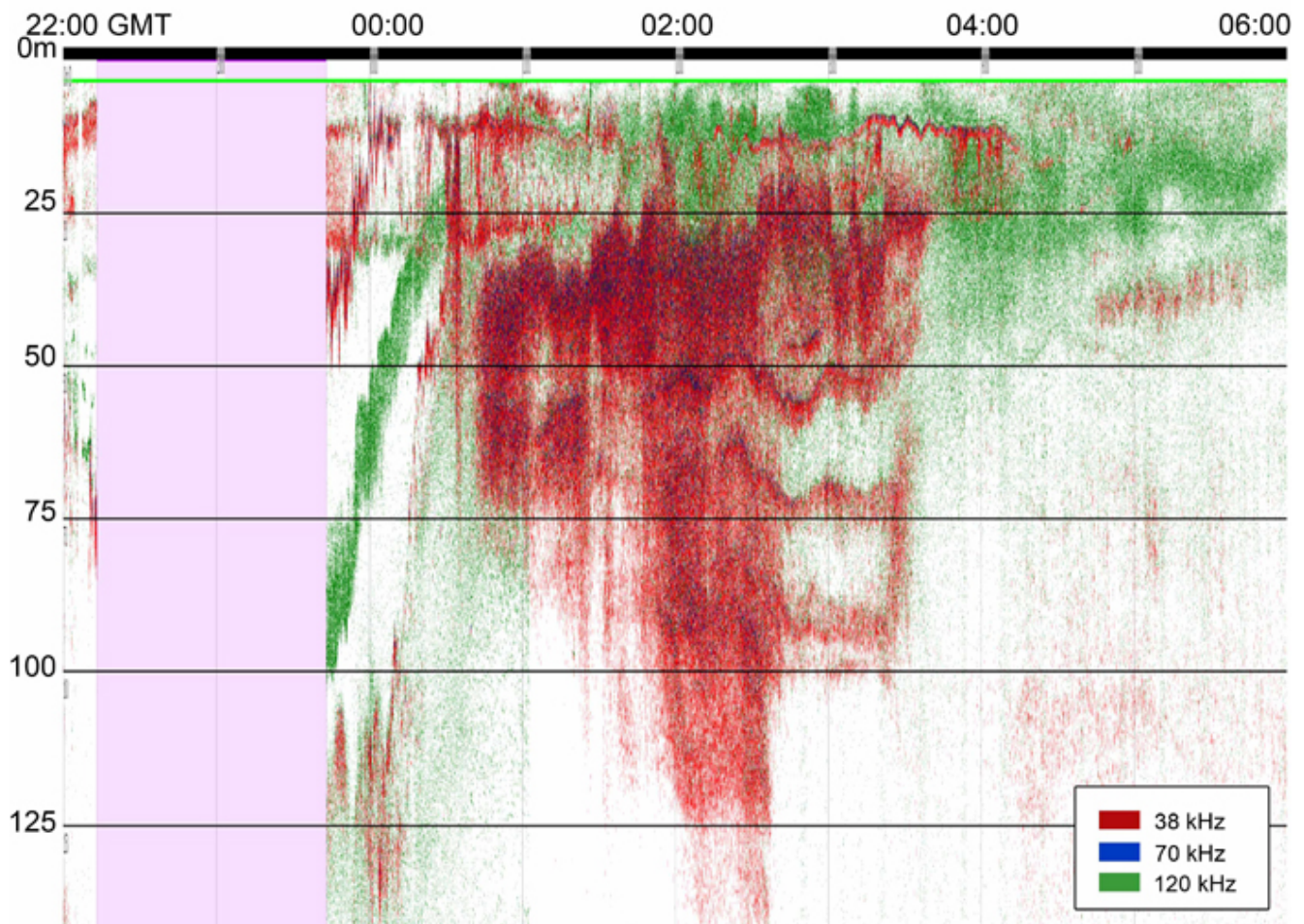


Figure 1. Data from 3-frequency Simrad scientific echosounder system, collected near a tagged pilot whale, *Globicephala melas*. Frequency differencing is a powerful tool for differentiating between clades of targets and when done in conjunction with the other research described in this report can be extremely powerful.